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(54) COOLING APPARATUS, SYSTEM, AND ASSOCIATED METHOD

KÜHLVORRICHTUNG, SYSTEM UND ZUGEHÖRIGES VERFAHREN

APPAREIL DE REFROIDISSEMENT, SYSTEME ET PROCEDE ASSOCIE

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- **DATABASE INSPEC [Online] THE INSTITUTION OF ELECTRICAL ENGINEERS, STEVENAGE, GB; 2004, KARIMI G ET AL: "Review and assessment of Pulsating Heat Pipe mechanism for high heat flux electronic cooling" XP002409418 Database accession no. 8117888 & THE NINTH INTERSOCIETY CONFERENCE ON THERMAL AND THERMOMECHANICAL PHENOMENA IN ELECTRONIC SYSTEMS 1-4 JUNE 2004 LAS VEGAS, NV, USA, vol. 2, 2004, pages 52-59 Vol.2, The Ninth Intersociety Conference on Thermal and Thermomechanical Phenomena In Electronic Systems (IEEE Cat. No.04CH37543) IEEE Piscataway, NJ, USA ISBN: 0-7803-8357-5**

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Description

BACKGROUND OF THE INVENTION

1) Field of the Invention

[0001] The present invention relates to a cooling system and, more particularly, to a cooling system employing a pulsating heat pipe for cooling a printed circuit board.

2) Description of Related Art

[0002] In avionics and other applications, printed circuit boards ("PCB's") are commonly mounted within a metallic chassis box. The heat generated by electronic devices carried by the PCB is dissipated by transfer to a metal (aluminum) wall of the chassis box through the PCB's. The heat is then sent to an external heat sink by conduction through the metal chassis wall, and is finally taken away by either cool air circulating about the heat sink or a cold plate. Because of high thermal resistance in the heat transfer path, the waste heat load generally increases with further operation, which in turn, leads to a larger temperature gradient (ΔT) between the electronic devices that are generating heat and the heat sink. This larger ΔT may adversely affect the performance of the electronic devices. Consequently, a more effective heat transfer approach had to be developed to address these thermal problems.

[0003] One advanced heat transfer approach is pulsating heat pipe (PHP) technology. A PHP is made with a looped or unlooped meandering capillary tube that forms a closed circuit, as shown in **FIG.1.** After partially filling a capillary tube that is maintained at a reduced pressure with liquid, the PHP reaches equilibrium by forming a plurality of vapor slugs separated by vapor bubbles, *i.e.*, regions of saturated liquid. In operation, heat is introduced in an evaporating region and is withdrawn from a condensing region. At steady state, heat transfer is achieved by continuous oscillatory movements from the evaporating region to the condensing region, which is caused by instant pressure imbalance among different turns. Both phase change and sensible heat exchanges are considered to participate in the heat transfer.

[0004] Since the late 1990's, PHP operating characteristics and mechanisms have been studied extensively, and this technology has been applied to more and more fields. For instance, the PHP technology has been employed to provide avionics device cooling, which has provided a significant reduction in thermal resistance, and employs the systems disclosed in U.S. Patent Nos. 4,921,041 5,697,428 to Akachi. In particular, and as shown in **FIG. 2** of the present application, an avionics chassis box was disclosed to house printed circuit boards and to include a tunnel plate heat pipe within a wall of the chassis box. Another wall of the chassis box may be a cold plate connected to a condenser to output the heat that has been transferred to the heat pipe from the PCB's. By positioning the heat pipe within the wall, the thermal resistance is reduced and the heat transportation capability is increased.

[0005] With the introduction of new and additional electronic devices that generate more heat in avionics and other systems, more waste heat is generated by the printed circuit boards. For instance, a new generation of electronic systems utilized in an avionics chassis may need to dissipate up to 1000 watts of total waste heat during operation. For example, each power supply module may generate and need to dissipate approximately 100 watts. The increasing heat dissipation requirements therefore cause a very large temperature gradient when traditional cooling solutions are utilized. Therefore, despite the above-mentioned improvements in avionics cooling including incorporating the PHP into the chassis box, additional improvements are desired that are capable of handling increasing amounts of waste heat.

[0006] It would therefore be advantageous to provide an improved cooling system for rapidly dissipating the increased amounts of waste heat generated by modem electronic systems. In this regard, it would be advantageous to provide a cooling system that provides a higher heat transfer capability and lower thermal resistance than conventional cooling systems. It would also be advantageous to provide a cooling system that offers a relatively simple construction and lower manufacturing cost than conventional cooling systems.

[0007] The document EP 1 363 481 A2 discloses a cooling apparatus. The document XP002409418 is an article entitled "Review and assessment or Pulsating that Pipe mechanism For high heat flux electronic cooling".

[0008] The document US 2004/0037045 A1 describes a thermal management system for an electronic device being provided a first thermal energy transfer assembly that is thermally coupled between a heat generating structure located on a circuit card and a first thermal interface surface spaced away from the heat generating structure.

BRIEF SUMMARY OF THE INVENTION

[0009] The problem is solved by an apparatus according to claim 1 and by a method according to claim 5.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

[0010] Having thus described the invention in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

FIG.1 is cross-sectional view of a pulsating heat pipe, according to one conventional technique;

FIG. 2 is a perspective view of an avionics cooling system having a pulsating heat pipe positioned within a wall of a chassis box , according to one prior art technique;

FIG. 3 is a cross-sectional view of a cooling system, according to one embodiment of the present invention;

FIG. 4 is an enlarged cross-sectional view of a portion of an exemplary cooling system;

FIG. 5 is a cross-sectional view of a portion of a cooling system, according to another embodiment of the present invention;

FIG. 6 is a cross-sectional view of a pulsating heat pipe positioned between two printed circuit boards, according to one embodiment of the present invention;

FIG. 7 is a cross-sectional view of a pulsating heat pipe positioned adjacent to a printed circuit board, according to one embodiment of the present invention;

FIG. 8 is a top cross-sectional view of a pulsating heat pipe positioned adjacent to a printed circuit board, according to one embodiment of the present invention;

FIG. 9 is a cross-sectional view of a cooling system, according to another embodiment of the present invention;

FIG. 10 is a flowchart illustrating a method of using the cooling system, according to one embodiment of the present invention; and

FIG. 11 is a graph plotting input power versus temperature gradient for various working fluids within the cooling system, according to one embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0011] The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which some, but not all embodiments of the invention are shown. Indeed, this invention may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will satisfy applicable legal requirements. Like numbers refer to like elements throughout.

[0012] Referring now to the drawings and, in particular to **FIG. 3** there is shown a cooling system **10,** according to one embodiment of the present invention. The cooling system **10** generally includes a plurality of printed circuit boards **12** ("PCB's") installed within a chassis box **13.** A portion of a pulsating heat pipe **14** ("PHP") is positioned adjacent a respective PCB and, more typically, between a pair of PCB's **12** within the chassis box **13.** The remaining portion of the PHP **14** is positioned adjacent to or within a wall of the chassis box **13.** As shown in **FIG. 3,** that portion of the PHP **14** located adjacent to or within the wall of the chassis box **13** may be thermally coupled to a heat sink, either directly or via a loop heat pipe **16** ("LHP").

[0013] Therefore, the cooling system **10** of one embodiment shown in **FIG. 3** may be generally divided into three stages: a first stage where the electronics are integrated with the PHP **14** (designated #**1**), a second stage where the PHP is integrated with the LHP **16** (designated #**2**), and a third stage where the LHP is integrated with a heat sink (designated #**3**). However, as discussed below, these general stages are not meant to be limiting and are illustrative only, as the cooling system **10** may employ various configurations in alternative embodiments of the present invention. Furthermore, although the cooling system **10** may be referred to herein as an avionics cooling system, it is understood that the cooling system is applicable to a variety of technologies that incorporate PCB's **12** installed within a chassis box **13**. For instance, the cooling system **10** is applicable to any number of industries that may incorporate a chassis box **13** having electrical components contained therein.

[0014] The chassis box **13,** as used herein, is any suitable box, housing, case, or pack for accommodating electrical components, such as PCB's **12.** An aerospace vehicle, for example, may incorporate several chassis boxes **13,** each containing various electrical components for providing different avionics functions. In this regard, several PCB's **12** may be installed within a single chassis box **13.** As such, the chassis box **13** typically includes a motherboard capable of receiving one or more PCB's, as well as other components and peripherals. The chassis box **13** is typically formed of a composite or metallic material, such as aluminum. Further, the chassis box **13** may be various sizes and configurations.

[0015] PCB's **12,** as also known to those skilled in the art, are circuit boards having opposing major surfaces that may receive, support, and interconnect one or more electrical components or other sources of heat (hereinafter generally referenced as "heat sources"). One major surface of each PCB **12** may be metallized, a composite material, or otherwise coated with a metallic material, while the opposite surface is capable of receiving one or more heat sources **18.** For instance, the heat sources **18** could be various computer and controller equipment or other electrical components that are supported by the PCB **12.** These components **18,** when in operation, act as heat sources that generate waste heat. For instance, **FIGS. 3-7** and **9,** depict embodiments in which the waste heat generated by various numbers and configurations of heat sources **18** may be dissipated with the cooling system **10** of the present invention. Moreover, the PCB's **12** are generally positioned parallel to one another within the chassis box **13** in a stacked configuration, although the PCB's could be arranged in any desirable orientation within the chassis box.

[0016] To remove this waste heat and avoid any degradation of the performance of the electrical components, a PHP **14** is positioned along a major surface of the PCB **12** for cooling the PCB. The PHP **14,** as known to those skilled in the art, could be any suitable PHP (See **FIG. 1**). Therefore, the PHP **14** includes a working fluid, such as water, acetone, or ethanol, that normally separates into different segments of liquid that are spaced apart and separated by vapor slugs within the PHP. The PHP **14** typically includes a meandering tube of capillary dimensions and many U-turns. In addition, the PHP **14** generally comprises an evaporator **20** and a condenser **22,** where heat received at the evaporator causes the liquid and vapor slugs to oscillate due to pressure pulsations created by the absorbed heat. As such, the pressure pulsations force the liquid and vapor slugs to move between the evaporator **20** and the condenser **22.** As heat is applied to the PHP **14** in the evaporator **20** such as by the transfer of heat from the PCB's **12,** at least some of the liquid is vaporized in the evaporator. Upon reaching the condenser **22,** in which the condenser region is generally cooler than the vapor arriving from the evaporator **20,** at least some of the vapor condenses into liquid. The volume expansion due to the vaporization and contraction due to the condensation causes the oscillating motion of the working fluid that sends vapor to the condenser **22** and returns liquid to the evaporator **20**. The oscillatory motion of the liquid and vapor slugs is self-sustaining as long as the heating and cooling conditions are maintained. Therefore, the PHP **14** is self-sufficient and does not require any external mechanical devices (*e.g.*, pumps) or energy to operate.

[0017] The PHP **14** of the present invention should not be limited to any particular configuration, as the PHP could be any number of sizes and configurations in additional embodiments of the present invention. For instance, the PHP **14** could be various dimensions, the tube could have various diameters and configurations, and the evaporator **20** and condenser **22** could have various lengths and numbers of turns. For example, the tube could have 5 turns and 10 pipes (See **FIG. 8**), and the PHP **14** could be approximately 9-30 cm in width. Moreover, the quantity of working fluid (*i.e*., filling ratio), types and properties of the working fluid, and tube material may be modified to generate different heat transfer results. For example, the filling ratio could be approximately 30-75%, while the tube could be a copper material with approximately 3-4 mm in outer diameter and a 1-2 mm in inner diameter. In addition, the PHP **14** could be open or closed-loop, oriented in various positions. Thus, the PHP **14** could be a closed loop, where the tube is joined end-to-end, such as that shown in **FIG. 3.**

[0018] According to advantageous embodiments of the present invention, however, the PHP **14** extends along and proximate to a major surface of the PCB **12** (or a pair of PCB's, as shown in **FIG. 3**). In order to provide relatively even cooling for the entire PCB **12** and its heat sources **18,** the PHP **14** generally extends along the surface of the PCB that is opposite the surface upon which the electrical components and other heat sources are mounted, although the PHP could be positioned in other locations proximate or adjacent to the PCB, as described below. As a result of this construction, the evaporator **20** region of the PHP **14** is generally formed by that portion of the PHP that extends along and absorbs heat from the PCB's **12,** while the condenser **22** region is typically remote from the PCB's, such as being positioned adjacent to a wall of the chassis box **13** or outside the chassis box.

[0019] **FIGS. 3** and **9** also illustrate that a LHP **16** may be incorporated into the cooling system **10.** The LHP **16,** as also known to those skilled in the art, is similar to the PHP **14** in that the LHP is passive and operates under pressure differences caused by heat. In this regard, the LHP **16** typically includes liquid and vapor lines **28,** an evaporator **24,** a condenser **26,** and a compensation chamber or reservoir (not shown). The evaporator **24** generally includes a wick structure having primary only or primary and secondary wicks, where heat acquired at the evaporator causes vapor to flow through the vapor line to the condenser **26.** In the embodiment shown in **FIG. 3**, the evaporator **24** of the LHP **16** is generally proximate to and in thermal communication with the condenser **22** of the PHP **14** such that heat is transferred from the PHP to the LHP. At the condenser **26,** the vapor is condensed, and the liquid travels through the liquid line back to the evaporator **24.** The compensation chamber is typically a two-phase reservoir that is responsible for maintaining the pressure and temperature within the LHP **16,** as well as the amount of working fluid in the system. The compensation chamber prevents the wick structure from drying out and collects any vapor formed in the evaporator **24.** The liquid line travels through the compensation chamber and into the evaporator **24**, where the liquid either wets the secondary wick or returns to the compensation chamber. The secondary wick is used to ensure that the primary wick is wet at all times.

[0020] The LHP **16** should not be limited to that described above or shown in **FIGS. 3** and **9,** as the LHP may be any number of materials, sizes, and configurations. For instance, the LHP **16** may have any number and configuration of meandering tubes in the condenser **26.** The liquid and vapor lines **28** may be various lengths and diameters such that the condenser **26** may be positioned in any desired position. For example, the condenser **26** could be incorporated as a deployable radiator, as known to those skilled in the art, such that the condenser may be used with a spacecraft or similar vehicle where varying amounts of cooling is necessary. In addition, **FIG. 9** demonstrates that the LHP **16** could be positioned adjacent to an outer surface of the chassis box **13** in an additional embodiment of the present invention.

[0021] Furthermore, the cooling system **10** typically employs a heat sink, such as cooling with air, liquid, fan, cold plate, or any other heat sink known to those skilled in the art. When a LHP **16** is utilized with the PHP **14,** the heat sink may be thermally coupled to the LHP and, in particular, to the condenser **26** of the LHP **16.** In the alternative, the heat sink may be coupled, or otherwise applied, directly to the PHP **14,** such that the LHP **16** is not required.

[0022] Referring to **FIGS. 3, 5,** and **6,** it is shown that the evaporator **20** of the PHP **14** is positioned between, and adjacent to, a pair of PCB's **12.** In particular, where each of the PCB's **12** include opposing surfaces and a thickness extending therebetween, the evaporator **20** is typically positioned along and adjacent to one of the opposing major surfaces of each of the PCB's. When one or more heat sources **18** are installed on a surface of the PCB's **12,** the evaporator **20** will typically be positioned on an opposite surface of the heat sources. Therefore, the PHP **14** is not limited to localized cooling of the PCB **12** in areas proximate to each heat source **18.** As the heat sources **18** operate and apply heat to the PCB's **12,** the evaporator **20** is capable of removing or otherwise transferring heat from the PCB's. The evaporator **20** may extend along the entire outer surface or a portion of the PCB's **12,** and as shown in **FIG. 7,** the evaporator **20** could be attached to a single PCB **12.** Although the PHP **14** is shown on a surface of the PCB **12** that is opposite the heat sources, the PHP could be positioned proximate or adjacent to the same surface as the heat source, and the PHP could alternatively be positioned within the PCB such that the PHP is embedded within the PCB.

[0023] The condenser **22** of the PHP **14** shown in **FIG. 3** is positioned within the wall of the chassis box **13,** such that the condenser does not take up any space within the interior of the chassis box. For instance, the condenser **22** could be positioned within a slot or similar type opening within the chassis box **13.** The condenser could alternatively be positioned adjacent, or otherwise proximate, to an inner or outer wall of the chassis box **13.** The PHP **14** of the illustrated embodiment is integrated with the LHP **16** such that the PHP and LHP are thermally coupled. In particular, the condenser **22** of the PHP **14** is typically integrated with the evaporator **24** of the LHP **16.** As such, the evaporator **24** of the LHP **16** is capable of further removing heat from the condenser **22** of the PHP **14** and transferring the heat to the condenser **26** of the LHP, where additional cooling may be applied through a heat sink. Thus, the LHP **16** is essentially an intermediary cooling and/or thermal transport system between the PHP **14** and the heat sink.

[0024] In the cooling system **10** of another embodiment shown in **FIG. 5,** a pair of PHP's **14** is positioned between respective PCB's **12.** The portion of the PCB's **12** opposite the PHP's **14** includes several heat sources **18.** The portion of the PHP **14** that is proximate to and extends along each of the PCB's **12** typically forms the evaporator **20.** The portion of the PHP **14** that extends beyond the PCB **12,** such as that portion within a connector **32,** typically forms the condenser **22.** Thus, the PHP **14** of this embodiment is substantially planar such that the evaporator **20** and condenser **22** of the PHP are collinear. Attached to each end of the PHP's **14** of **FIGS. 5** and **6** are connectors **32**, typically formed of metal or another conductive material. The connectors **32** are typically received within PCB clamps **34.** The connectors **32** may extend the entire length of each PHP **14,** as shown in **FIG. 8,** and are adaptable to one (See **FIG. 7**) or more (See **FIGS. 5** and **6**) PCB's **12.** In this embodiment, a LHP **16** is attached to an outer surface of the chassis box **13,** and as shown in **FIG. 9,** there may be more than one LHP attached to the chassis box. Thus, each PHP **14** may include a condenser **22** on each end that is thermally coupled to respective LHP's **16.** As such, heat removed by the evaporator **20** of the PHP **14** and transferred to the condenser **22** of the PHP, may be further transferred to the connectors **32** and PCB clamps **34,** through the chassis wall **13,** and to the evaporators **24** of the LHP's **16.**

[0025] In regards to the aforementioned cooling systems **10,** the evaporator **20** of the PHP **14** may be attached to the PCB's **12** with an adhesive, solder, fastener, or similar technique that secures the evaporator directly to the surface of respective PCB's. In addition, the PHP **14** could be secured to the PCB **12** by clamping or fastening the PHP within pre-made grooves defined in the PCB. Direct attachment to the PCB's **12** facilitates conduction of heat to the evaporator **20** of the PHP **14,** and also allows the evaporators to be positioned within the chassis box **13** without taking up undue space.

[0026] Similarly, each of the PHP's **14** may be secured to the chassis box **13** using any number of techniques. For instance, as described above, connectors **32** may be sized and configured to fit over and engage opposing ends of each PHP **14,** such that the connectors may mate to PCB clamps **34** attached to the interior surface of the chassis box **13.** The connectors **32** could be further fastened to the PCB clamps **34,** or simply positioned between the PCB clamps. Thus, the connectors **32** may be customized for a particular PHP **14,** and the connectors could be simply inserted on the ends of the PHP, or the connectors could be press fit or attached to the PHP with an adhesive, solder, fastener, or similar technique. The connectors **32** and PCB clamps **34** may be any suitable conductive material, such as copper or aluminum. Furthermore, a high-conductivity epoxy may be used to attach each PHP **14** to the PCB **12.** Also, the condenser **22** could be attached with an adhesive, fasteners, clamps, or similar fastening technique directly to an inner surface of the wall of the chassis box **13.** Moreover, with respect to **FIG. 9,** an adhesive, fasteners, or similar technique could also be employed to secure the LHP **16** to the outer surface of the chassis box **13.**

[0027] It is understood that the cooling systems **10** illustrated in **FIGS. 3** and **5-9** are not meant to be limiting, as the cooling system may comprise various configurations in alternative embodiments of the present invention. For instance, the arrangement of the PCB's **12,** PHP **14,** and LHP **16** may be arranged in, and is unaffected by, different orientations. Thus, the cooling system **10** is capable of cooling the PCB's **12** irrespective of orientation, which is useful for applications, such as avionics, where orientation and gravitational forces may be constantly changing. Furthermore, although the PHP **14** shown in **FIG. 3** is a flat PHP having a substantially L-shaped configuration with the evaporator **20** extending generally perpendicular to the condenser **22,** and the PHP **14** shown in **FIGS. 5-9** includes an evaporator **20** that is collinear to the condenser **22,** the PHP may be configured in any suitable manner for accommodating various cooling systems.

[0028] Furthermore, although only a pair of PCB's **12,** one PHP **14,** and one LHP **16** is shown in **FIG. 3,** there may be any number of PCB's, PHP's and LHP's for accommodating various electronic applications and achieving desired cooling properties. For example, **FIG. 5** demonstrates that there may be four PCB's **12** and two PHP's, while **FIG. 9** illustrates that there may be six PCB's, three PHP's, and a single LHP **16.** Thus, individual evaporators **20** may be positioned between pairs of PCB's, as explained above, and condensers **22** may be positioned adjacent to inner walls of the chassis box **13** such that each PHP **14** is independent of one another. Moreover, each PHP **14** may be thermally coupled to one or more LHP's **16,** or more than one PHP may be thermally coupled to a single LHP. In addition, the LHP **16** may be positioned adjacent to an outer wall of the chassis box **13** or at various locations remote from the chassis box.

[0029] **FIG. 4** illustrates an example , where a pair of sheets **30** formed of a metal or other thermally conductive material is positioned adjacent to, and between, respective PCB's **12,** while the PHP **14** is positioned adjacent to, and between, the pair of sheets. Thus, the sheets **30** extend along the major surfaces of the PCBs **12** and the PHP **14** extends between the pair of sheets. The PCB's **12** typically have a high thermal resistance due to poor electrical conductivity properties. As a result, positioning the sheets **30** adjacent to both the PCB's **12** and PHP **14** increases the thermal conduction between the PCB's and PHP such that thermal resistance is reduced and heat may be more easily removed from the PCB's and transferred to the PHP. As such, the sheets **30** may be any suitable material that is capable of conducting heat, such as copper.

[0030] **FIG. 4** also illustrates that the cooling system **10** is capable of being employed without a LHP **16.** It would typically be advisable to have a heat sink directly applied to the condenser **22** of the PHP **14** in those instances where a LHP **16** is not utilized to remove the waste heat. However, it is understood that the cooling system **10** depicted in **FIG. 4** may also employ a LHP **16** if so desired.

[0031] **FIG. 10** illustrates a flowchart of the steps involved in carrying out the method of the present invention. Generally a chassis box **13** is provided (block 31), and at least one PCB **12** is installed within the chassis box (block 33). At least one heat source **18** is positioned on a surface of the PCB (block 35). Further, at least a portion of at least one PHP **14,** *i.e.,* the evaporator **20,** is positioned either along and proximate to a major surface of the PCB or is embedded within the PCB (block **36**). While the PHP **14** could extend adjacent to the PCB **12,** the sheets **30** could be positioned between each PCB **12** and PHP **14** such that the PHP is proximate to the PCB even though the PHP is spaced from the PCB by the sheet. Heat is absorbed by the PCB **12** from the PCB and the one or more heat sources **18** carried by the PCB, which causes pressure pulsations within the evaporator **20** of the PHP, which begins the cooling process (block **38**). As a result, heat is transferred from the PCB **12** by the PHP **14** and out of the chassis box **13** (block **40**). In particular and as explained above, the connectors **32** and PCB clamps **34** conduct waste heat from the condenser **22** of the PHP **14,** through the chassis wall **13,** and to the evaporator **24** of the LHP **16**. Thereafter, a heat sink could be thermally coupled to the LHP **16** to further remove waste heat.

[0032] Preliminary experimental results have demonstrated that the cooling system **10** of the present invention is more effective than traditional cooling techniques. **FIG. 11** illustrates a graph of input power versus temperature gradient, where input power corresponds to power applied through the heat sources **18,** and temperature gradient corresponds to the temperature difference between the heat sources and the heat sink. **FIG. 11** shows that for an input power of 55, 110, and 165 watts and a fill ratio of 40% for various working fluids, the heat transfer performance of each of the working fluids in the PHP **14** is better than simply using a copper sheet to transfer heat to the heat sink.

[0033] Embodiments of the present invention therefore provide a cooling system **10** capable of cooling PCB's **12** installed within a chassis box **13.** The cooling system **10** is adaptable to a variety of technologies, including avionics, and may be customized for various cooling needs. The cooling system **10** of one advantageous embodiment employs a PHP **14** that takes up a minimal amount of space by positioning the evaporator **20** between pairs of PCB's **12,** and positioning the condenser **22** within, or adjacent to, the wall of the chassis box **13.** In addition, PHP's **14** are generally known to have a lower manufacturing cost, have a simple and lightweight internal structure, and have a higher heat transfer capability than conventional avionics cooling techniques. Thus, the cooling system **10** is capable of reducing the temperature gradient between the heat sources **18** and the heat sink, as well as reducing the thermal resistance between the PCB's **12** and PHP **14.** Because of the improved heat transfer characteristics, the cooling system **10** is better capable of handling the increasing demands of new electronic devices in avionics and other technologies. As such, the reliability and performance of electronics will be improved due to the reduction of temperature of the heat sources **18** and PCB's **12.**

[0034] Many modifications and other embodiments of the invention set forth herein will come to mind to one skilled in the art to which this invention pertains having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

Claims

1. A cooling apparatus (10) comprising:

   a chassis housing (13);
   at least one printed circuit board (12) having opposed major surfaces and positioned within the chassis housing (13);
   at least one heat source (18) positioned on one major surface of the printed circuit board (12); and
   a pulsating heat pipe (14) having at least one portion positioned to either extend along and proximate to one of the major surfaces or be embedded within the printed circuit board (12), wherein opposing ends of the pulsating heat pipe (14) are coupled to the chassis housing (13), and wherein the pulsating heat pipe (14) is capable of transferring heat from the printed circuit board (12),
   and a loop heat pipe (16) thermally coupled to the pulsating heat pipe (14), the loop heat pipe (16) comprising an evaporator (24) and a condenser (26), wherein a condenser (22) of the pulsating heat pipe (14) is positioned within a wall of the chassis housing (13).

2. The apparatus according to claim 1, wherein the evaporator (24) of the loop heat pipe (16) is thermally coupled to the condenser (22) of the pulsating heat pipe (14).

3. The apparatus according to claim 1, wherein the evaporator (20) of the pulsating heat pipe (14) is positioned adjacent to the major surface of the printed circuit board (12) opposite the heat source (18).

4. The apparatus according to claim 1, further comprising a pair of printed circuit boards (12), wherein the pulsating heat pipe (14) is positioned between the pair of printed circuit boards (12).

5. A method for cooling at least one printed circuit board (12), the method comprising:

   providing a cooling system (10) comprising:

   - a chassis housing (13);
   - at least one printed circuit board (12) having opposed major surfaces and positioned within the chassis housing (13);
   - at least one heat source (18) positioned on one major surface of the printed circuit board (12); and
   - a pulsating heat pipe (14) having at least one portion positioned to either extend along and proximate to one of the major surfaces or be embedded within the printed circuit board (12);
   - positioning a condenser (22) of the pulsating heat pipe (14) within a wall of the chassis housing (13) [C5L43-45];
   - thermally coupling a loop heat pipe (16) to the pulsating heat pipe (14), the loop heat pipe (16) comprising an evaporator (24) and a condenser (26);

   transferring heat from the printed circuit board (12) with the pulsating heat pipe (14); and
   transferring heat away from the printed circuit board (12) and out of the chassis housing (13) by movement of the heat through the pulsating heat pipe (14).

6. The method according to claim 5, wherein providing further comprises positioning the loop heat pipe (16) adjacent to an outer surface of the pulsating heat pipe (14), such that the loop heat pipe (16) is thermally coupled to the pulsating heat pipe (14).

7. The method according to claim 6, further comprising transferring heat from the pulsating heat pipe (14) to the loop heat pipe (16).

Patentansprüche

1. Kühlvorrichtung (10), die aufweist:

   ein Chassis-Gehäuse (13);
   zumindest eine Leiterplatte (12) mit sich gegenüberliegenden Hauptflächen, wobei die Leiterplatte (12) innerhalb des Chassis-Gehäuses (13) positioniert ist;
   zumindest eine Wärmequelle (18), die auf einer Hauptfläche der Leiterplatte (12) positioniert ist; und
   ein pulsierendes Wärmerohr (14), das zumindest einen Abschnitt aufweist, der positioniert ist, um sich entweder entlang und nahe einer der Hauptflächen zu erstrecken oder der in die Leiterplatte (12) eingebettet ist, wobei sich gegenüberliegende Enden des pulsierenden Wärmerohrs (14) an das Chassis-Gehäuse (13) gekoppelt sind, und wobei das pulsierende Wärmerohr (14) Wärme von der Leiterplatte (12) transferieren kann,
   und ein Schleifenwärmerohr (16), das thermisch an das pulsierende Wärmerohr (14) gekoppelt ist, wobei das Schleifenwärmerohr (16) einen Verdampfer (24) und einen Kondensator (26) aufweist, wobei ein Kondensator (22) des pul-

sierenden Wärmerohrs (14) in einer Wand des Chassis-Gehäuse (13) positioniert ist.

2. Vorrichtung nach Anspruch 1, wobei der Verdampfer (24) des Schleifenwärmerohrs (16) thermisch an den Kondensator (22) des pulsierenden Wärmerohrs (14) gekoppelt ist.

3. Vorrichtung nach Anspruch 1, wobei der Verdampfer (20) des pulsierenden Wärmerohrs (14) angrenzend an die Hauptfläche der Leiterplatte (12) gegenüberliegend zur Wärmequelle (18) angeordnet ist.

4. Vorrichtung nach Anspruch 1, die ferner ein Paar aus Leiterplatten (12) aufweist, wobei das pulsierende Wärmerohr (14) zwischen dem Leiterplattenpaar (12) positioniert ist.

5. Verfahren zum Kühlen von zumindest einer Leiterplatte (12), wobei das Verfahren aufweist:

Vorsehen eines Kühlsystems (10), das aufweist:

- ein Chassis-Gehäuse (13);
- zumindest eine Leiterplatte (12) mit sich gegenüberliegenden Hauptflächen, die innerhalb des Chassis-Gehäuses (13) positioniert ist;
- zumindest eine Wärmequelle (18), die an einer Hauptfläche der Leiterplatte (12) positioniert ist; und
- ein pulsierendes Wärmerohr (14) mit zumindest einem Abschnitt, der positioniert ist, um sich entweder entlang und nahe einer der Hauptflächen zu erstrecken oder der in die Leiterplatte (12) eingebettet ist;
- Positionieren eines Kondensators (22) des pulsierenden Wärmerohrs (14) in einer Wand des Chassis-Gehäuses (13) ;
- thermisches Koppeln eines Schleifenwärmerohrs (16) an das pulsierende Wärmerohr (14), wobei das Schleifenwärmerohr (16) einen Verdampfer (24) und einen Kondensator (26) aufweist;

Transferieren von Wärme von der Leiterplatte (12) mit dem pulsierenden Wärmerohr (14); und Transferieren von Wärme weg von der Leiterplatte (12) und aus dem Chassis-Gehäuse (13) heraus durch eine Bewegung der Wärme durch das pulsierende Wärmerohr (14).

6. Verfahren nach Anspruch 5, wobei das Vorsehen des Weiteren ein Positionieren des Schleifenwärmerohrs (16) angrenzend an eine äußere Fläche des pulsierenden Wärmerohrs (14) aufweist, so dass das Schleifenwärmerohr (16) thermisch an das pulsierende Wärmerohr (14) gekoppelt ist.

7. Verfahren nach Anspruch 6, das des Weiteren ein Transferieren von Wärme von dem pulsierenden Wärmerohr (14) an das Schleifenwärmerohr (16) aufweist.

Revendications

1. Appareil de refroidissement (10), comprenant :

un boîtier de châssis (13),
au moins une carte à circuits imprimés (12) ayant des surfaces majeures opposées et positionnée dans le boîtier de châssis (13) ;
au moins une source de chaleur (18) positionnée sur une surface majeure de la carte à circuits imprimés (12) ; et
un tube à chaleur pulsée (14) ayant au moins une portion positionnée soit de manière à s'étendre le long et à proximité de l'une des surfaces majeures soit de manière à être noyée dans la carte à circuits imprimés (12), des extrémités opposées du tube à chaleur pulsée (14) étant accouplées au boîtier de châssis (13), et le tube à chaleur pulsée (14) étant capable de transférer de la chaleur depuis la carte à circuits imprimés (12),
et un tube à chaleur en boucle (16) accouplé thermiquement au tube à chaleur pulsée (14), le tube à chaleur en boucle (16) comprenant un évaporateur (24) et un condenseur (26), un condenseur (22) du tube à chaleur pulsée (14) étant positionné à l'intérieur d'une paroi du boîtier de châssis (13).

2. Appareil selon la revendication 1, dans lequel l'évaporateur (24) du tube à chaleur en boucle (16) est accouplé thermiquement au condenseur (22) du tube à chaleur pulsée (14).

3. Appareil selon la revendication 1, dans lequel l'évaporateur (20) du tube à chaleur pulsée (14) est positionné à côté de la surface majeure de la carte à circuits imprimés (12) en face de la source de chaleur (18).

4. Appareil selon la revendication 1, comprenant en outre une paire de cartes à circuits imprimés (12), le tube à chaleur pulsée (14) étant positionné entre la paire de cartes à circuits imprimés (12).

5. Procédé de refroidissement d'au moins une carte à circuits imprimés (12), le procédé comprenant :

la fourniture d'un système de refroidissement (10) comprenant :

- un boîtier de châssis (13) ;

- au moins une carte à circuits imprimés (12) ayant des surfaces majeures opposées et positionnée dans le boîtier de châssis (13) ;
- au moins une source de chaleur (18) positionnée sur une surface majeure de la carte à circuits imprimés (12) ; et
- un tube à chaleur pulsée (14) ayant au moins une portion positionnée soit de manière à s'étendre le long et à proximité de l'une des surfaces majeures soit de manière à être noyée dans la carte à circuits imprimés (12) ;
- le positionnement d'un condenseur (22) du tube à chaleur pulsée (14) à l'intérieur d'une paroi du boîtier de châssis (13) [C5L43-45};
- l'accouplement thermique d'un tube à chaleur en boucle (16) au tube à chaleur pulsée (14), le tube à chaleur en boucle (16) comprenant un évaporateur (24) et un condenseur (26) ;
le transfert de chaleur de la carte à circuits imprimés (12) avec le tube à chaleur pulsée (14) ; et

le transfert de chaleur à l'écart de la carte à circuits imprimés (12) et hors du boîtier de châssis (13) par mouvement de la chaleur à travers le tube à chaleur pulsée (14).

6. Procédé selon la revendication 5, dans lequel la fourniture comprend en outre le positionnement du tube à chaleur en boucle (16) à côte d'une surface externe du tube à chaleur pulsée (14), de telle sorte que le tube à chaleur en boucle (16) soit accouplé thermiquement au tube à chaleur pulsée (14).

7. Procédé selon la revendication 6, comprenant en outre le transfert de chaleur depuis le tube à chaleur pulsée (14) jusqu'au tube à chaleur en boucle (16).

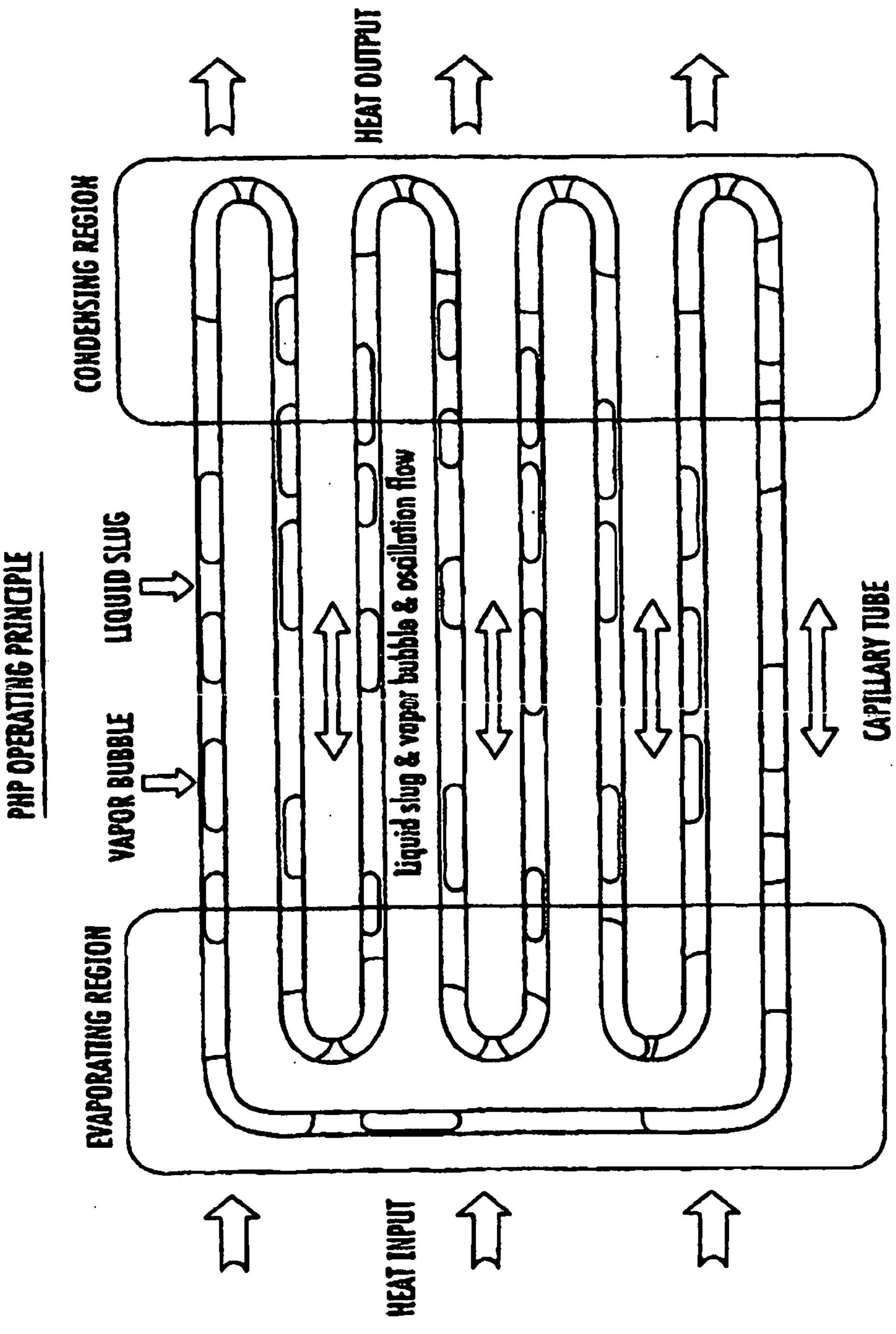

FIG. 1
(PRIOR ART)

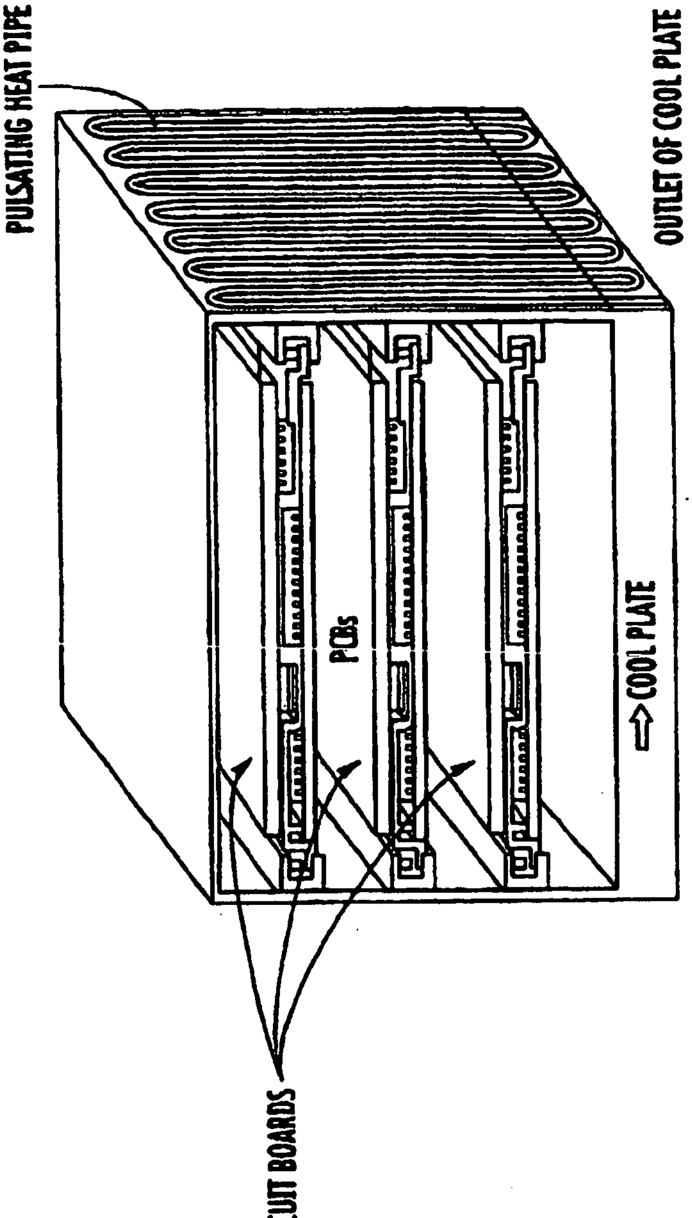

FIG. 2
(PRIOR ART)

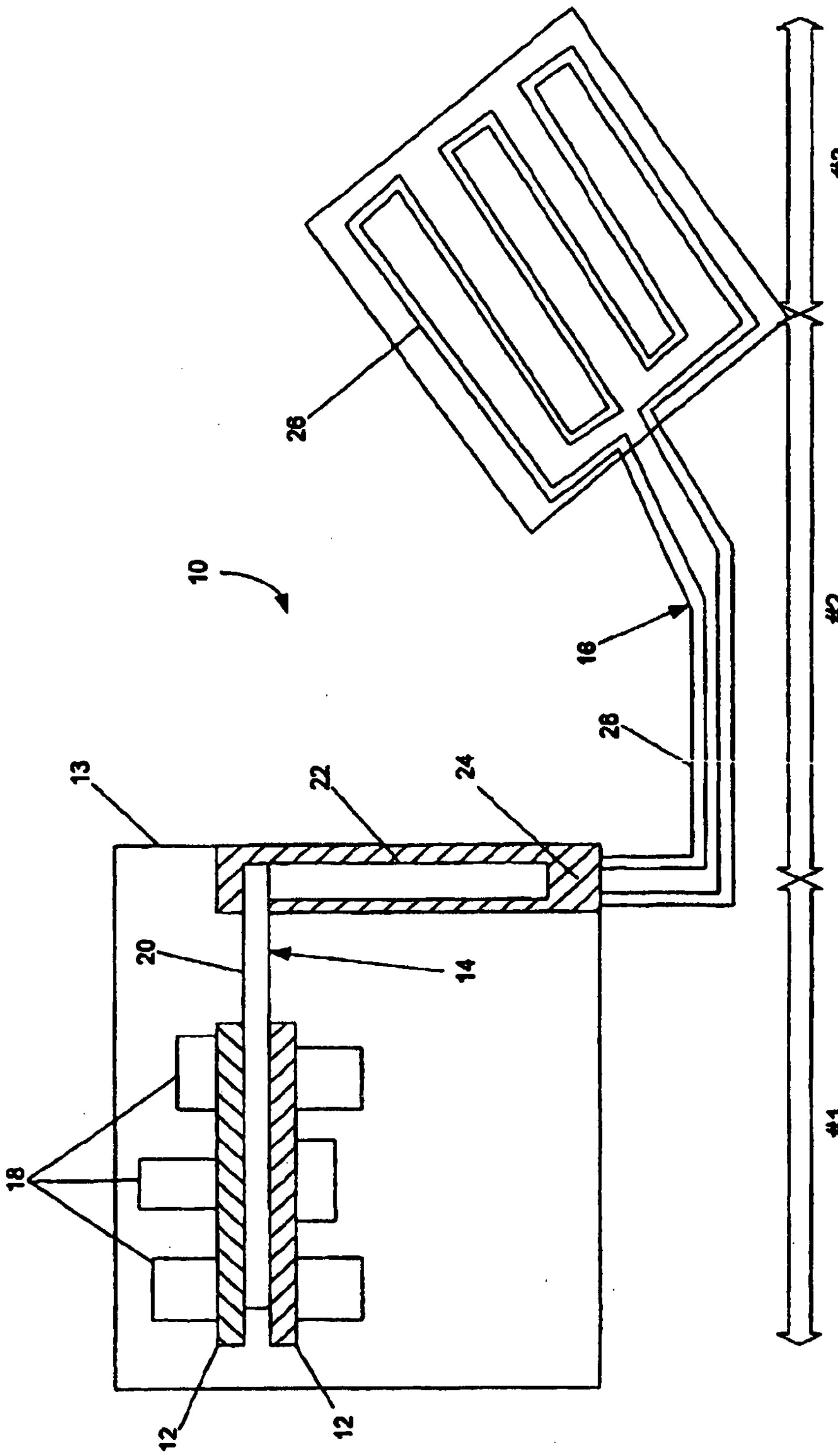

FIG. 3

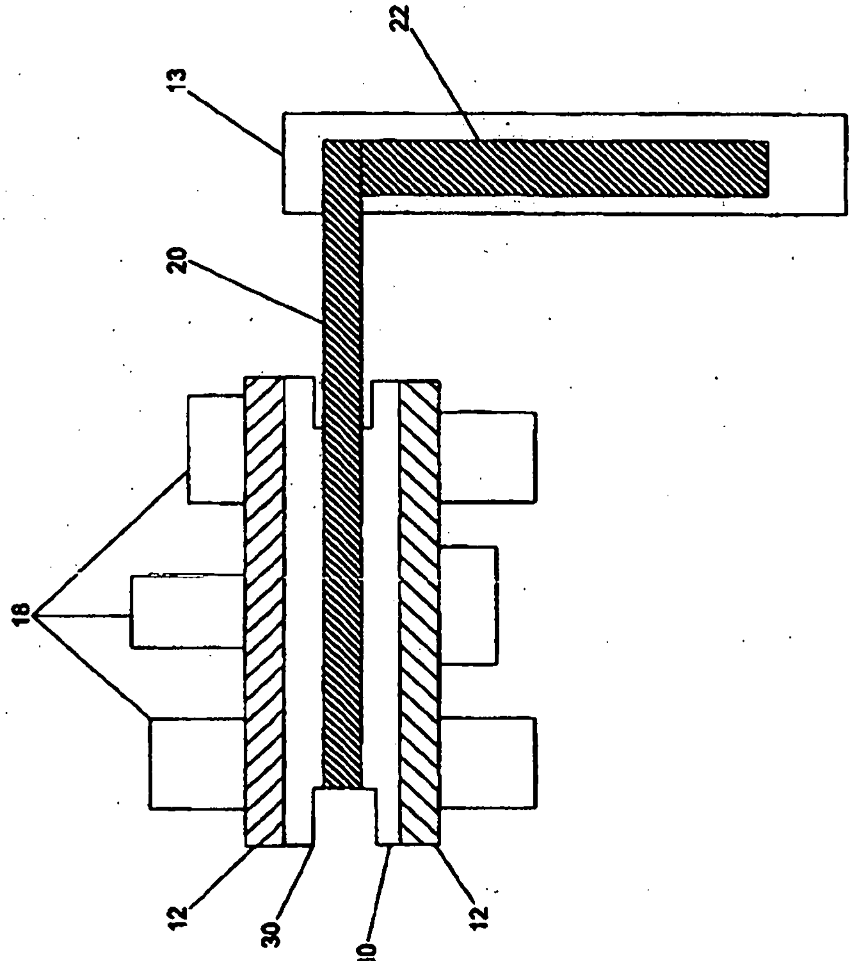

FIG. 4

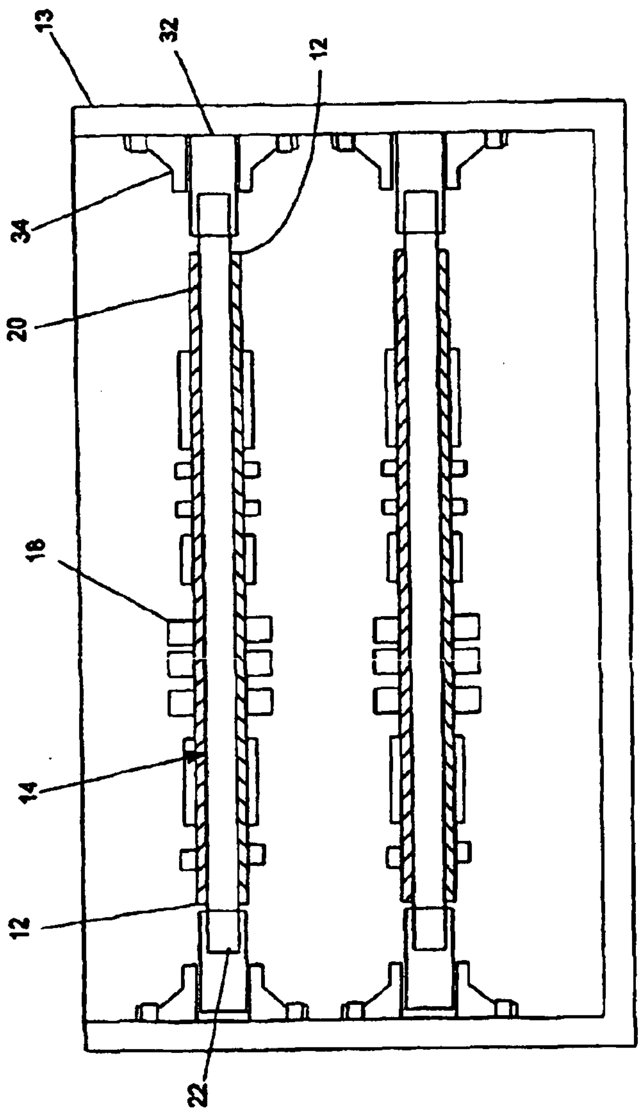

FIG. 5

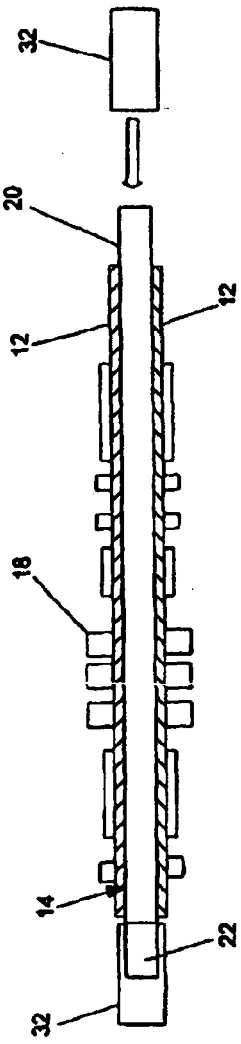

FIG. 6

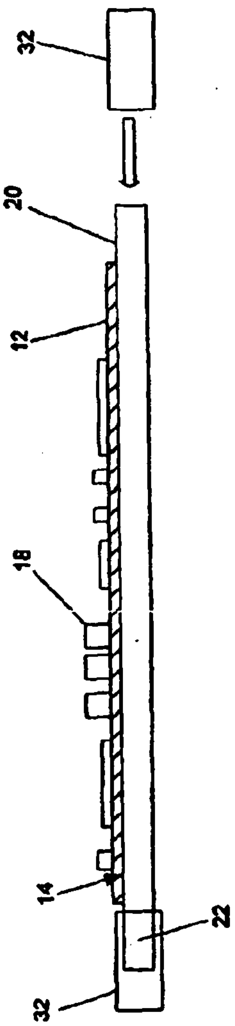

FIG. 7

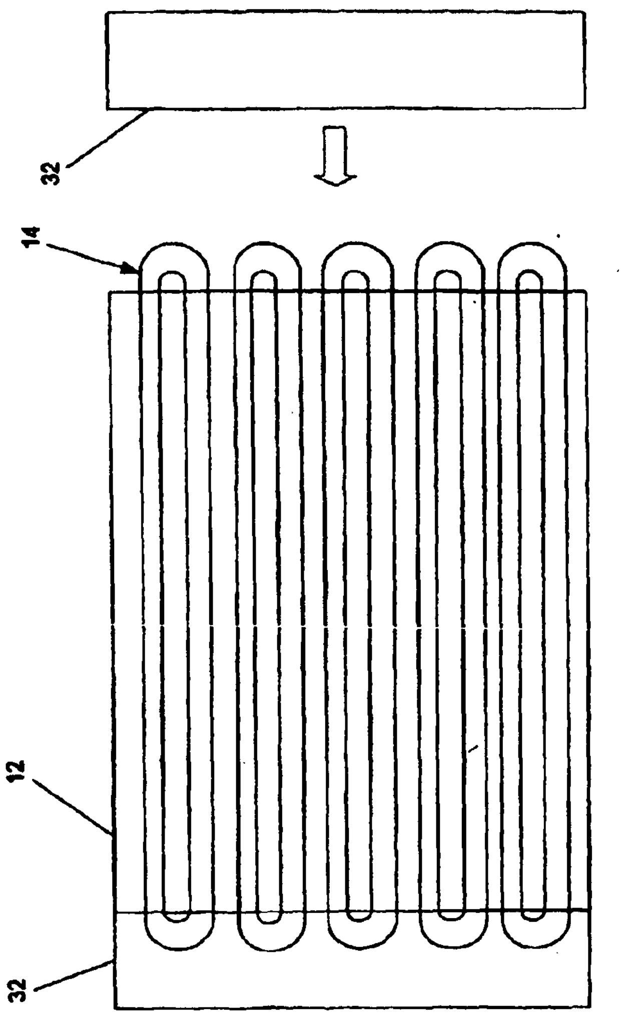

FIG. 8

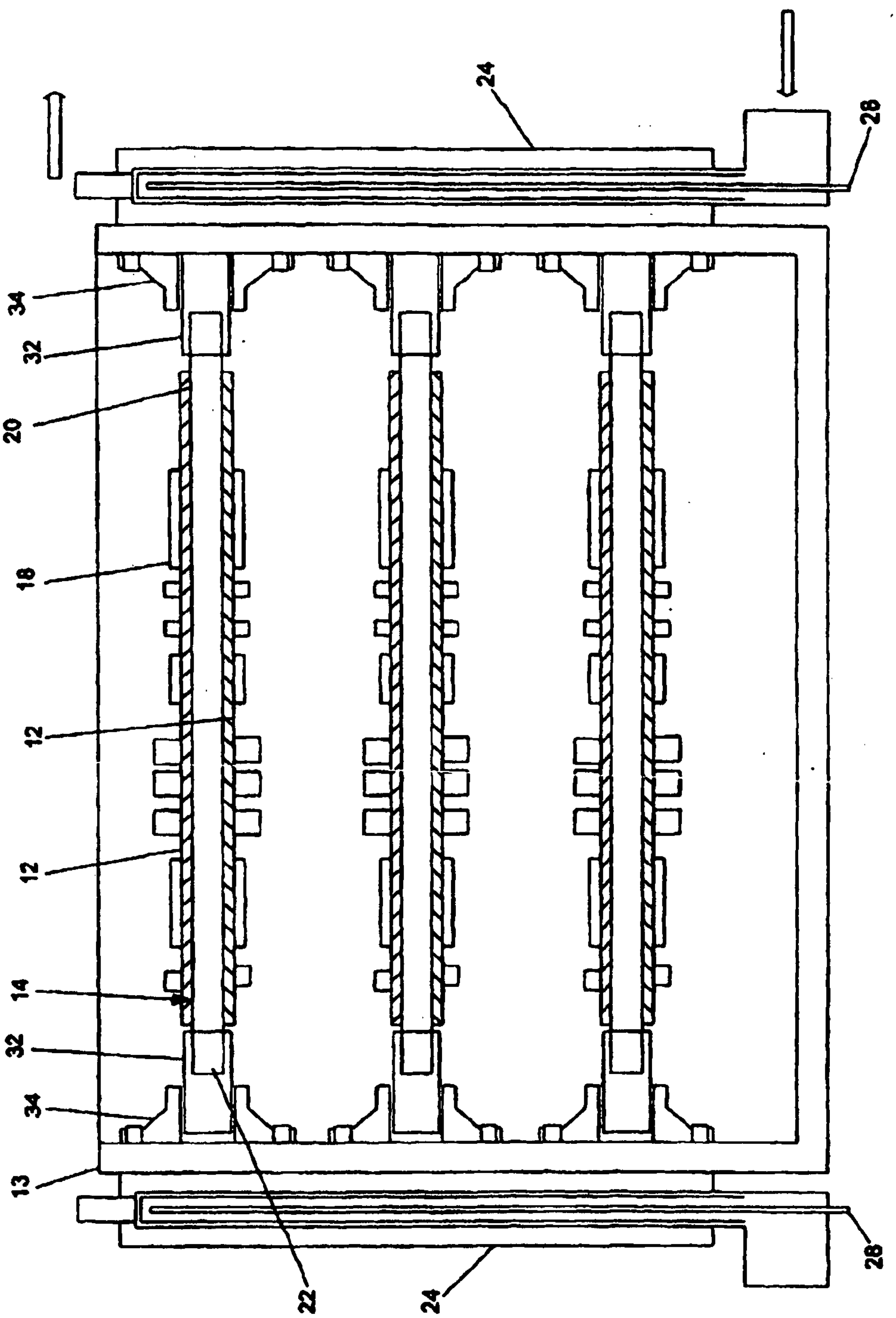

FIG. 9

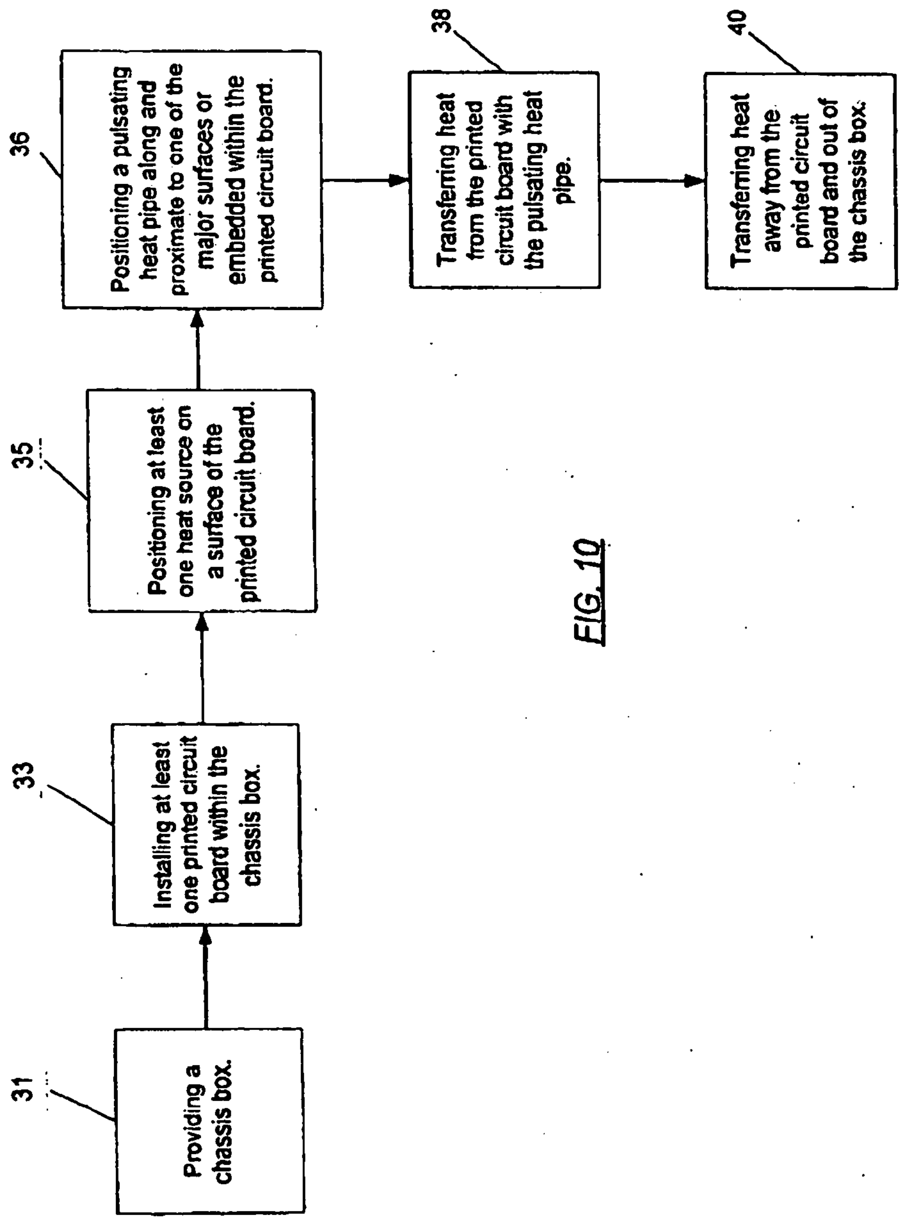
31
Providing a chassis box.
33
Installing at least one printed circuit board within the chassis box.
35
Positioning at least one heat source on a surface of the printed circuit board.
36
Positioning a pulsating heat pipe along and proximate to one of the major surfaces or embedded within the printed circuit board.
38
Transferring heat from the printed circuit board with the pulsating heat pipe.
40
Transferring heat away from the printed circuit board and out of the chassis box.

FIG. 10

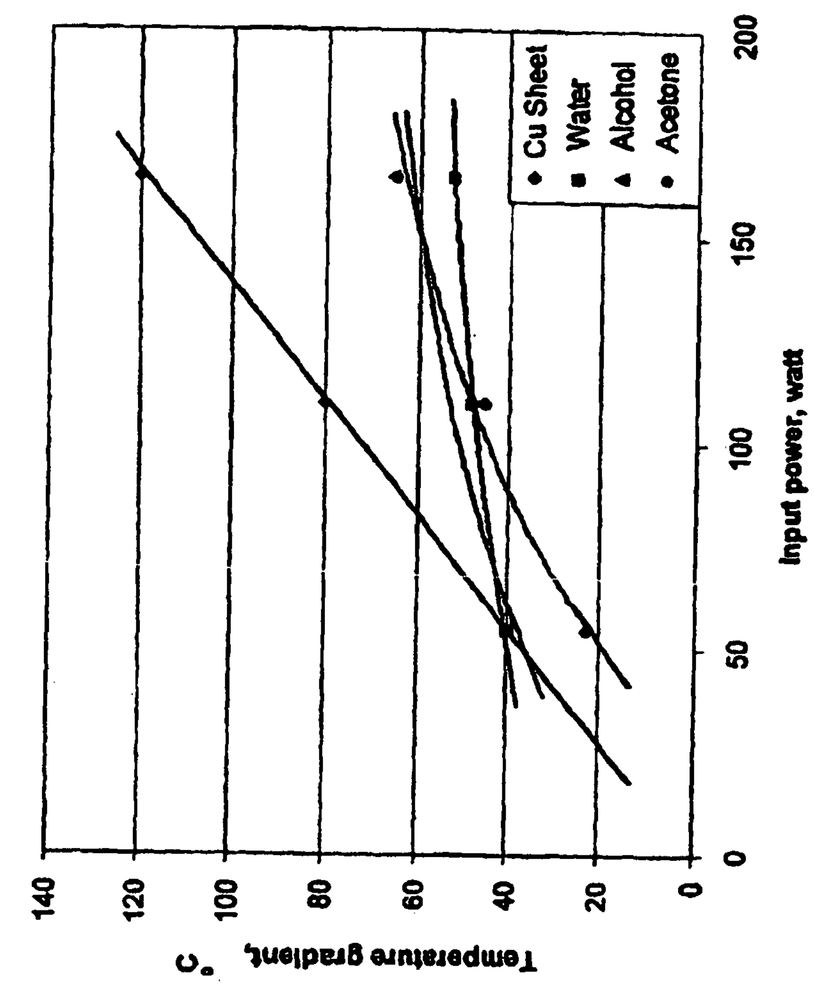
Temperature gradient, °C
140
120
100
80
60
40
20
0
0
50
100
150
200
Input power, watt
Cu Sheet
Water
Alcohol
Acetone

FIG. 11

REFERENCES CITED IN THE DESCRIPTION

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- US 5697428 A, Akachi **[0004]**
- EP 1363481 A2 **[0007]**
- US 20040037045 A1 **[0008]**